Missouri Department of Natural Resources (DNR)

and

U.S. Environmental Protection Agency (EPA)

Office Of Solid Waste And Emergency Response (OSWER)

Contamination Characterization Through Airborne Hyperspectral Imagery (HSI) Pilot Project

Final Report

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1. PROJECT OVERVIEW AND BACKGROUND

1.1. Overview

The Missouri Department Of Natural Resources, the department, obtained a grant from the U.S. Environmental Protection Agency (EPA), Office Of Solid Waste And Emergency Response (OSWER), to conduct a pilot project to evaluate applications of airborne Hyperspectral Imagery (HSI) to characterize ground contamination. The Pilot Project used the Civil Air Patrol's (CAP) new Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance (ARCHER) airborne HSI sensor and aircraft in anticipation of the proposed deployment of 16 ARCHER aircraft throughout the U.S. Multispectral Imagery (MSI) and HSI have been available from satellites and airborne platforms, both government and commercial, in increasingly better resolution and spectral coverage for several decades. Many applications to environmental issues have been studied and applied. This project focused on CAP's mission of disaster relief and emergency response; and therefore, ARCHER's potential role in Environmental Emergency Response (EER). At the same time, the Pilot Project explored other environmental contamination characterization applications.

ARCHER HSI has real-time and potential post analysis applications for EER. An existing real-time capability to detect and alert on anomalies makes the system suitable for locating propane tanks, drums, and other containers of potential contaminates after floods or other disasters. HSI has been used to locate petroleum spills and may be able to identify other surface contamination releases. The Pilot Project used ARCHER to collect HSI along the plume track from the June 2005, Praxair industrial gas fire in St. Louis. Even though the flight occurred 45 days after the fire, and much of the asbestos from the exploding tanks had been cleaned up from beneath the plume, analysis of the imagery indicated that substances with a signature similar to the area around the Praxair facility were found along the plume and scattered in other nearby areas. Follow-on site sampling was not feasible, but the analysis suggests an application for similar EER situations. The analysis is provided in Section 3.4.3. ARCHER should be used through State and Federal Emergency Management Agencies (SEMAs and FEMA) as often as possible to develop the tasking process and broaden the HSI applications

The most promising application for contamination characterization appears to be wide-area field screening for detectable contaminants, such as mine tailings, tiff and other waste. Several 3 km x 3 km areas in two lead mining districts were imaged. Site Project Managers (PM) identified known mine waste in the imagery. The University of Missouri (UMC) analysts then developed a signature from the known area and applied it, through imagery tools, to the remainder of the imagery. The processing highlighted other potentially contaminated areas. The PMs advised that some of the highlighted areas were known to be contaminated, while others were new, but in suspect areas. Only limited ground truth confirmation was feasible. Because of the potential impact that this application could have on the state and EPA's mine-scarred land inventory, which covers most of southern Missouri, follow-on ground truth confirmation is being considered. Follow-on collection will be attempted if the ground truth initiative confirms the findings. The analysis is provided in Section 3.4.3.

Other potential site-specific characterization capabilities also exist and will continue to be evaluated using existing imagery. Leachate seeps from a closed landfill were identified along a creek and bluff in areas where a major study had located several seeps. The seeps that had been identified during the study were highlighted, as well as others that were not located by the study, but were in areas where the study group suspected they would surface. One surface seep, previously remediated, has apparently reappeared. The site has been closed and the study concluded; therefore, confirmation has not been feasible. However, the PM was confident the information would be useful to support future initiatives at the landfill. Limited feedback was also received on analysis of other sites. The process appears to work for some contamination and site conditions. This report provides results and recommendations based on preliminary analysis. There was not sufficient funding for extensive analysis of any one contaminant or condition. Collection was maximized for the two days that ARCHER was available, so that HSI data would be available for follow-on studies and use by other state and federal agencies.

1.2. Project Background

Following the accidental or deliberate release or dispersion of hazardous materials through a natural or man-made disaster, it is critical to locate and characterize the contamination as quickly as possible. Many substances have a unique spectral signature that can be used for characterization. HSI systems have tens to hundreds of detectors for individual contiguous bands of the visible and InfraRed (IR) spectrum, and can provide data to potentially identify these substances. Airborne HSI systems could potentially help to define the nature and extent of contamination at relatively low concentrations across a large area in near real-time. If so, it could support wide area screening and allow field personnel to quickly determine priorities, response needs and clean-up strategies. Beyond emergency response, HSI has many proven and postulated environmental analytical applications.

Missouri, and other states, will soon have access to an airborne HSI system through CAP. Headquarters CAP, National Technology Center, is acquiring and deploying 16 HSI configured aircraft, designated ARCHER, that will be stationed in CAP regions for Homeland Security (HS), disaster relief, search and rescue, and other “to be defined” missions. Under existing Memorandums of Understanding (MOUs), CAP aircraft support FEMA and SEMA during major emergencies, and natural and man-made disasters, with photographic and visual reconnaissance. ARCHER will eventually be available to FEMA/SEMA for emergencies, and to state and federal agencies for other environmental applications.

The ARCHER prototype aircraft completed operational test and evaluation mid-2005. CAP was interested in expanding applications of the HSI sensor and ARCHER missions. The department proposed this Pilot Project to evaluate applications of ARCHER HSI to characterizing chemical contamination on the ground, much the same way that the EPA’s Airborne Spectral Photometric Environmental Collection Technology (ASPECT) HSI thermal imaging system characterizes contaminants in the air to support emergency response. ARCHER collected imagery of known contaminated sites in Missouri in early August 2005. UMC's remote sensing staff, through the UMC-DNR Missouri Resource Assessment Partnership (MoRAP), began analysis shortly thereafter. The following report provides the criteria used by OSWER to evaluate proposed projects and this Project's inputs and results, the Project's objectives and accomplishments, and lessons learned.

2. EVALUATION CRITERIA

OSWER used the following criteria to select pilot projects for the October '04 - September '05 period. Included are the department application inputs and results.

2.1. Fosters either innovative approaches toward environmental challenges or a more innovative culture or organizational system within the targeted organization.

Input:

Airborne HSI has been used commercially for identifying oil-impacted surfaces, land use classification, mineral exploration, hazardous waste remediation and a variety of other characterization projects. This project researches existing hyperspectral characterization initiatives for application to Missouri DNR's (MDNR) requirements; develops a collection plan against known chemically contaminated sites with known surface contamination levels; conducts an airborne hyperspectral imagery collection mission against identified sites; analyzes the collected data to evaluate the ability of the sensors to distinguish the contaminants of interest; and develops new signatures for follow-on missions. The project expands an existing capability to other forms of chemical contamination.

Results:

Several studies were identified where HSI was successfully used to characterize areas contaminated by mining operations. The studies were used to support Pilot Project planning and analysis, and are attached (Attachment 1) for information. A workshop was held in April 2005, to provide an overview of HSI and ARCHER, discuss applicable contamination conditions, and identify sites for collection. Collection planning and execution are addressed in the report. ARCHER missions were flown August 8-9, 2005, against a variety of contaminated sites. The HSI was analyzed by UMC and the results provided in the report.

2.2. Provides a process to measure and evaluate the impact of the pilot and desired outcome.

2.2.1. Outcome - Expand the use of airborne HSI for wide-area chemical contamination characterization

Input:

2.2.1.1 Measure. Locate existing hyperspectral signatures of chemical contaminates that provide repeatable results during the Pilot Project. The identification of applicable existing signatures is Phase I of the project. The higher the percent of existing signatures that can be easily applied to Missouri's contaminants the greater the potential for states to develop and share the signatures, and for airborne systems, particularly CAP's, to be applied to the characterization process. Twenty percent repeatable results would make this phase of the project successful.

Results:

Because of the difference in contamination and conditions in sites identified in Phase I studies and the lack of a library of signatures for the Missouri sites and conditions selected, there were no signatures available for comparison. However, signatures developed during analysis at mining sites in southwest Missouri were repeatable from one mining area to another. Some adjustments had to be made in applying the signatures due to flight paths and lighting conditions. Those are explained in the analysis section.

Input:

2.2.1.2 Measure. Develop new signatures from known contaminated areas at selected test sites. The application of this system to contamination characterization is dependent on the development of signatures and algorithms that can automatically identify the contaminant and support determination of the extent. Phase II and III of the project will identify sites where the contamination levels can be established, and collect imagery of those sites. One new signature would make this phase successful and demonstrate the potential application.

Results:

Unique signatures were developed for each site and condition. However, differing types of contamination and environmental conditions would make it difficult to use most signatures in a library or signature database. The process for developing signatures in response to emergency situations and site conditions was developed and is repeatable. The process is described in the report. The use of a handheld spectrometer would probably improve signature development and is recommended for future use of ARCHER.

2.2.2. Outcome - Improve emergency response through airborne HSI collection and near real-time analysis

Input:

Measure. Develop algorithms that show promise of automated identification of the target chemicals. Support to emergency response will depend on near real-time identification and characterization. Phase IV of the project is the development of algorithm(s) that match signatures with collected imagery, and operate with sufficient speed to allow on-scene responders to identify the chemicals and determine the extent of contamination. This may be particularly applicable to terrorist created contamination where the responders have not entered the area and need an initial assessment of the contaminants. EPA’s ASPECT sensor provides this capability for many airborne contaminants. One algorithm that shows positive results and establishes the process for developing additional algorithms would make this phase successful.

Results:

The Praxair industrial gas storage fire in St. Louis provided an opportunity to evaluate ARCHER and HSI for EER. The ARCHER mission was several weeks after the fire, rain had washed away some of the contaminants, and cleanup was underway. However, an existing End-Member analytical process was used by UMC in IMAGINE to identify substances that may have been spread by the fire plumb. Results were provided to EER personnel, and are discussed in the report.

2.3. Builds or strengthens partnerships with state, tribal and local governments; other federal programs/initiatives; and/or other external stakeholders.

Input:

Airborne HSI systems have been evolving over the past few years. Some environmental applications have been developed and evaluated. However, evaluation, development, and routine and emergency use of the capabilities by states, tribal units and local governments have been limited because of the expense of commercial collection and analysis. CAP’s acquisition of an airborne HSI system and eventual deployment to all regions puts the potential use of these systems for environmental characterization within reach of all states, tribal units and local governments. If CAP's initiative and partnership is to be successful, the states will need to be proactive in evaluating and developing the applications. This Pilot Project expands on limited evaluations by other states and commercial entities and evaluates HSI against a broader spectrum of routine and emergency chemical contamination requirements. The results of this Pilot Project will be shared with CAP and other states and tribal units through various associations and working groups.

Results:

A web page has been established for the Pilot Project:

http://www.dnr.mo.gov/env/hwp/hsi/hsi-project.htm

This report and results of the project will be published on the web page and information about its availability provided to governmental agencies through various associations and working groups. EPA will publish the results through its lines of communication. ARCHER can only be used by government agencies, but non-government agencies can apply the results of the project to commercial HSI companies.

2.4. Potential for pilot results to be applied across geographic regions or programs.

Input:

CAP plans to deploy an airborne hyperspectral imaging and analysis system in every CAP region. The signatures developed in this project will likely work in other areas, possibly with some adjustments for local area and soil conditions. The algorithms should be adaptable.

Results:

Contamination signatures were different for each area or condition for this project. A single signature of mining waste in southwest Missouri did appear to identify similar waste in three separate areas within the same geographic area. Continued testing would be required to determine if that same signature would also work in other areas. It would not have worked for southeast Missouri mining waste because of the different mineral composition in the two areas. However, processes for developing the signatures, processing the ARCHER data and performing the analysis were developed, and would be applicable across geographic areas.

2.5. Likelihood of producing preliminary short term results within six months and longer-term results and or/measurable progress within one year of initiation of the project.

Input:

This project is scheduled to complete Phases I, identifying existing signatures and algorithms, and II, developing target sites and collecting ground data, within the first six months. The final phases, Phase III, collecting new imagery of the target set, and Phase IV, analyzing the data and testing signatures against existing data, will be completed within one year of initiation, environmental conditions permitting. Ground condition and cover will be a factor in scheduling collection. A follow-on initiative of testing the algorithms against new imagery of suspected sites, and testing with emergency response personnel will be conducted when CAP deploys ARCHER to this region.

Results:

ARCHER was not available until early August 2005. Within two months, UMC had developed procedures to convert the ARCHER output to a usable form for their commercial imagery analysis software, and all PMS for the imaged sites had reviewed their imagery. Dialog between UMC and the PMs helped develop contamination signatures that were used for analysis. Signatures at several sites showed promise of immediate application, and the results were provided to the PMs for verification. The most promising was identification of mine waste in southwest Missouri where high concentrations of zinc in tailings inhibit vegetation growth and provide an identifiable signature. Overlay of locations of mine related activity from an existing database on the HSI coverage of the areas showed a high degree of correlation, and identified potential sites that were not in the mine database. Ground cover does limit the application of HSI where vegetation stress is not an identifiable factor. Discussions with technical staff indicates that vegetation stress has potential, but contamination has differing effects on vegetation, and those differences are a major factor. This Project does not address vegetation stress. There was not sufficient funding or time to collect a second set of imagery for verification.

3. OBJECTIVES AND ACCOMPLISHMENTS

The following are the objectives from the Pilot Project application and accomplishments for the four phases of the HSI Pilot Project.

3.1 Phase I - MSI/HSI Research

Objectives:

This Phase included research of existing applications of multi-spectral and hyperspectral imagery (MSI/HSI) to environmental contamination characterization, and contacts with other states, universities research centers and commercial imagery collectors. The objective was to compile a list and documentation where available, of completed or on-going MSI/HSI environmental projects.

Accomplishments:

- UMC contacted five members of academia regarding HSI projects and studies. One research initiative on remediation and risk assessment of lead contaminated soils in Southwest Missouri proposed using HSI. The proposed sensor was NASA's AVIRIS system. The project was not funded due to poor results shown by ground-truth. Several studies identified during Phase I report on the application of an HSI sensor, similar to ARCHER, to mine waste characterization. The sensor, Compact Airborne Spectrographic Imager (*casi)*, provides approximately the same spectral coverage as ARCHER.

- UMC conducted literature reviews for environmental applications of HSI. The following titles applied.

- Aspinall, R. J., W. Andrew Marcus, and Joseph W. Boardman (2002*). Considerations in Collecting, Processing, and Analyzing High Spatial Resolution Hyperspectral Data for Environmental Investigations.*

- Lèvesque, J., V. Singhroy, K. Staenz, and D. Bolton (1997). *Site Characterization of Mine Tailings at the INCO Copper Cliff Tailings Impoundment Area using casi Imagery*.

- Josée Lévesque, Tom Szerdi, Karl Staenz, Vern Singhroy, *Spectral Band Selection form casi Data for Monitoring Mine Tailings Site Rehabilitation*

- Hector Jasso, Peter Shin, Tony Fountain, and Deana Pennington, *Using Wavelets for Classification of Hyperspectral Images*.

- Josée Lévesque, Robert A. Neville, Karl Staenz, *Preliminary Results on the Investigation of Hyperspectral Remote Sensing for the Identification of Uranium Mine Tailings*.

- J. Lévesque, K. Staenz, and T. Szeredi, *The Impact of spectral Band characteristics on Unmixing of Hyperspectral Data for Monitoring Mine Tailings site Rehabilitation.*

- Josée Lévesque, Karl Staenz, Jiali Shang, Bob Neville, Paul Yearwood, Vern Singhroy, *Temporal Monitoring of Mine Tailings Revegetation Using Hyperspectral Data, Sudbury, Ontario*

- Jiali Shang, Josée Lévesque, Karl Staenz, Philip Howarth, Bill Morris, and Lisa Lanteiqne, *Investigating casi Responses to Different levels of Tailing Oxidation: Inco Copper Cliff Tailings Area, Northern Ontario, Canada.*

• Jiali Shang, Josée Lévesque, Philip Howarth, Bill Morris, Karl Staenz, and Paul Yearwood, *Preliminary Investigation of Acid Mine Drainage Detection Using casi Data, Copper Cliff, Ontario, Canada.*

• P.J. Zarco-Tejada, J.R. Miller, G.H. Mohammed, T.L. Noland, and P.H. Sampson, *Vegetation Stress Detection through Chlorophyll a+b Estimation and Fluorescence Effects on Hyperspectral Imagery*

• I. Reusen, L. Bertels, W. Debruyn, B. Deronde, D. Fransaer, S. Sterckx, VITO - Flemish Institute for Technological Research, Mol, Belgium, *Species Identification and Stress Detection of Heavy-Metal Contaminated Trees*

- A summary of contacts, a list of HSI literature and copies of selected papers are at Attachment 1.

3.2 Phase II - Site Selection

Objectives:

This Phase identified a variety of known contaminated sites for HSI collection.

Accomplishments:

- HSI Site Database. Department and UMC Project personnel began a series of meetings in January to discuss how to collect and organize information on contaminated sites for HSI collection. The project web page, described below, included information on how to submit contaminated sites for consideration in collection planning. The following is a summary of meeting discussions.

January 12 - UMC/MoRAP (Dr. Dave Diamond, Dr. Clayton Blodgett, Ronnie Lea) and department (Nick Carbone) Project personnel met for initial discussions of options for diversifying the types of contamination and environmental issues to address in the Project. Federal and state agencies that may be interested in participating in the Project were also discussed, as a means of expanding site selection. A framework for researching environmental applications of HSI and potential contacts was established.

February 16 - UMC/MoRAP (Dr. Dave Diamond, Dr. Blodgett, Ronnie Lea) and department (Nick Carbone, Branden Doster) Project personnel, as well as a representative from U.S. Geological Survey (USGS) (Chris Schmitt) and the DNR director's office (Joe Engeln) met to discuss lead mining and other potential Project sites. The state and USGS have an on-going study on lead mining contamination in the Missouri lead belt and tri-state lead mining areas. Several contamination and abandoned mining problems exist that provide options for evaluating HSI applications. Approaches for developing ground truth and collecting data for various contamination problems were discussed.

March 16 - In preparation for the March 16 meeting, an email was sent to a selection of state and federal agencies explaining the Pilot Project and outlining the site development process. All were invited to nominate sites for the Project, and site information requirements were defined. UMC/MoRAP and department Project personnel met to define the fields for the site database, and further discuss site nominations that had been made to date. A database structure and initial input of sites resulted. A map of the initial site database, database structure and list of sites is enclosed.

- HSI Pilot Project Site Development Workshop. Part of the planned site development process was a workshop for state and federal agencies to describe the Project, define remote sensing and HSI, describe CAP's ARCHER and EPA's ASPECT systems, and discuss potential HSI applications for a variety of contamination conditions. The workshop was held April 7, 2005 at the Truman Building in Jefferson City, MO. Approximately 30 personnel from a variety of state and federal agencies, including emergency management/response offices, attended. Briefings were informative, and CAP and EPA representatives introduced ARCHER and ASPECT to many that were unaware of their capabilities. Six state PMs briefed contamination conditions at their sites. The briefings were followed by a dialog between ARCHER project personnel, the PM presenters and the audience regarding potential HSI applicability. Five of the sites were included in follow-on collection. The Workshop report is at Attachment 2. Workshop briefings can be downloaded from the Project web page.

- Web Page. A web page was established on the department's web site under the Hazardous Waste Program (HWP), *Hyperspectral Imagery Pilot Project*. The web address is provided in Section 2.3. The web page describes the project, and provides Workshop briefings and report. A copy of this report, including the HSI collection process and results of analysis, will also be posted.

3.3 Phase III - HSI Collection

Objectives:

This Phase collected HSI of 14 contaminated sites or areas using CAP's ARCHER system.

Accomplishments:

The critical event for the Project was collecting the HSI. In February, the department requested three ARCHER missions, based on optimal vegetation and weather conditions. A copy of the department's request is at Attachment 3. CAP completed ARCHER test and evaluation in the spring of 2005, and took delivery of the first operational aircraft in the summer. Col. Drew Alexa, CAP ARCHER Project Officer, advised that an operational aircraft and newly trained crew would not be available for the Project until September, 2005. At that time, the department expected a routine extension of the grant beyond September 30, 2005, leaving time for imagery analysis. However, in late July, EPA notified all grantees that a funding rescission would preclude extensions of existing grants. Mr. Pete Kalisky, CAP Headquarters National Operations Center (NOC) was contacted and asked if the collection mission could be moved up to early August to allow time for imagery analysis and reporting. CAP HQ responded by bringing together an experienced crew from around the country and the ARCHER prototype aircraft, and deployed to Jefferson City, August 7-9, 2005.

The Missouri Army National Guard (MoNG) provided space in their hanger at the Jefferson City airport for CAP, UMC/MoRAP and department personnel to plan and execute two days of collection missions. Coordination with COL Clark, MoNG, State Aviation Office, through SGT Lubbert and CWO Smith obtained permission to use the mission planning area for the Project. CWO Smith, MoNG, responsible for hanger operations, was a gracious host, ensuring that communications, flight planning and other needs were addressed. In addition to having a space for mission planning, using the NG spaces allowed NG and other state and federal agencies in the Jefferson City area to observe ARCHER and its capabilities. Figures 1-3 show

Figure 1 - ARCHER Ground Station in MoNG Mission Planning area

the NG planning area.

Coordination with Mr. Doug Lauf, Missouri Office of Administration (OA), State Flight Operations, obtained permission to house the aircraft in the state's hanger at the Jefferson City airport. The MoNG hanger did not have space for the aircraft. Mr. Lauf also arranged for fuel. The fuel was charged to OA and reimbursed by the Project, reducing the direct expenses for CAP. The aircrew arrived in Jefferson City, Sunday, August 7. They were briefed on the Project's objectives, and provided charts of the target areas and graphics of the sites selected for Monday's missions. The ARCHER sensor operators then entered the flight data and site coordinates in their handheld ARCHER Trac computer in preparation for the morning mission. (See the ARCHER brief on the web page for details of the ARCHER system.)

Figure 2 - ARCHER Flight Planning

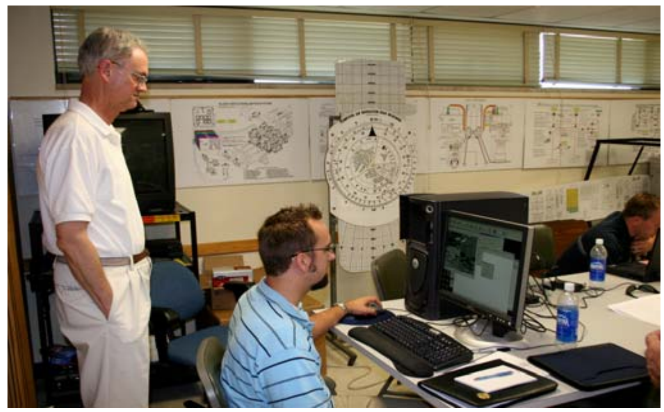


Figure 3 - UMC IMAGINE Hyperspectral Imagery Workstation

On Monday, August 8, the aircraft was taxied from the OA hanger to the MoNG hanger, where the ARCHER ground station was off-loaded and set up in the mission planning area. When ARCHER deploys from its home base, all airborne and ground equipment is carried in the aircraft. Extra crewmembers join the aircraft at the deployment site. The UMC Remote Sensing personnel also set their IMAGINE HSI workstation up in the planning area. The objective was to download the HSI data from the aircraft to the ARCHER ground station, where Dr. Kershenstine, CAP, would review it for quality and completeness, and the imagery strips identified logged by site for future reference. The data was then to be transferred to the IMAGINE workstation to ensure it could be processed and analyzed. The UMC personnel conducted limited review of the imagery on site. All of the analyses for the Project was done using IMAGINE at MoRAP. A description of the procedures for processing the HSI data by UMC, and the review and analysis with site PMs is described in Phase IV.

Figure 4 - ARCHER sensor and workstation

Figure 5 - ARCHER on the Ramp at the MoNG Hanger Jefferson City

Seven sites were covered on the August 8, morning mission: JZ Landfills, Weldon Spring Site Remedial Action Project, Tyson Valley Powder Farm, Praxair Inc. Industrial Gas Plant Fire, industrial flood sites in St. Louis, Herculaneum Lead Smelter, and Hematite Radiological Site. Transit time from Jefferson City to the St. Louis area was about 45 minutes, making the first mission approximately four hours. It became apparent that cramped conditions in the aircraft and the day's warm temperatures would limit collection for the afternoon flight. Attachment 4 provides a graphic depiction of the flight path and sites. These graphics were used for flight crew briefings.

Due to transit times and lighting conditions, the Monday afternoon mission was reduced to a single pass of a portion of the Big River contaminated with lead mine tailings, and area coverage of Mineral Point and Potosi, where lead contamination from mining operations has been detected at high levels in residential areas. The aircraft normally flies at 2500 ft, resulting in imagery with a one-meter resolution. A low-level pass was conducted in Potosi to evaluate the application of higher resolution imagery to detection of lower concentrations of contamination. The lower altitude provided 60cm resolution. Attachment 4 provides a graphic depiction of the planned sites and those that were collected (1 - Big River, 7 - Mineral Point, 8 - Potosi).

One mission was flown Tuesday morning to southwest Missouri. The primary sites were three residential areas affected by lead mining. Southwest Missouri, the Tri-State mining area, is one of three Missouri metal mining locations, each with a different mixture of lead and other metals. The Tri-State area, which includes southeast Kansas and northern Oklahoma, has extensive tailings piles with high concentrations of zinc. Three locations were imaged, Wentworth, Aurora and Grandby. Each location covered an approximately 2 km x 2 km area. Two tire dumps were also imaged during the transits to and from Jefferson City, but the initial review on the ARCHER ground station indicated that the desired results were not obtained. Attachment 4 provides a graphic depiction of the planned sites and those that were collected (10 - Grandby, 11 - Wentworth, 12 - Aurora).

3.4 Phase IV - HSI Analysis

Objectives:

This Phase included analysis of the ARCHER imagery and development of HSI signature(s) of contamination where applicable. The objective was to determine if the HSI signature(s) could be used at other suspected or known similarly contaminated sites, and tested against follow-on HSI collection. Lack of funding and time precluded additional HSI collection. MSI/HSI signatures provided by other agencies in Phase I would be evaluated against imagery collected under this program. No signatures were identified in Phase I.

Accomplishments:

3.4.1 Data Pre-Processing:

Once the imagery was delivered from the flight crew, each image strip (consisting of one minute of data acquisition) had to be identified and cataloged. The image data were then separated based on which site was imaged. Each image strip then needed to be corrected for distortion caused by aircraft movement (Figure 6). Using our standard image processing software, LEICA Geosystems ERDAS Imagine, no straightforward method existed to correct the Archer imagery. Therefore, proprietary

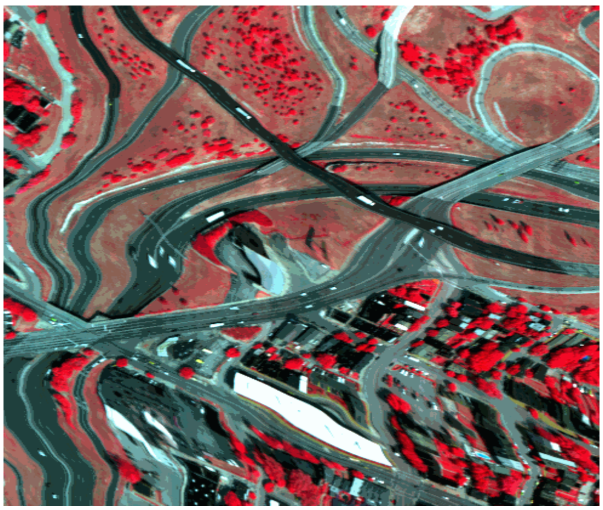


Figure 6 - Image from ARCHER Ground Station

Figure 7 - Geocorrected Image

software was obtained from Space Computer Corporation (SCC) that exploited the inertial navigation system (INS) and global positioning system (GPS) information that was collected at the same time the ARCHER imagery was collected. SCC developed the ground station that is used by the Civil Air Patrol (CAP) to process Archer imagery. The SCC software uses the INS and GPS information as inputs and outputs an Image Geometric Model (IGM) file. The IGM file provides geolocation information for each pixel in an image. The IGM file can then be used to correct the distortion present in the raw ARCHER imagery. Use of the IGM file required us to purchase another piece of image processing software, ENVI, from Research Systems, Inc. The imagery was then georeferenced in ENVI using the IGM file to create a geographic lookup table (GLT) file; a file which applies projection information to each pixel to produce a roughly geocorrected image (Figure 7). Using ENVI and the IGM and GLT files allowed the imagery to be corrected for distortion caused by the aircraft. At this point the data was still not in a form where further processing could be applied. The output images were now roughly placed in spatial reference to each other; however, they needed to be precision rectified in order to perform large area analysis. Without precision rectification, site images would not be properly aligned with one another. Because further analysis was going to be performed using ERDAS Imagine software and the analysts were already proficient in precision rectification using Imagine software, the images were converted to an Imagine image file format for the rectification procedure.

Each image strip was precision rectified to 2003 National Agriculture Imagery Program (NAIP) color-infrared imagery. NAIP imagery for Missouri was collected with a one-meter spatial resolution and delivered as county mosaics. A maximum Root Mean Square (RMS) error of 0.5 pixels was allowed. The lack of quality ground control points for some image strips caused those image strips to be less accurately rectified than others. This was due to the rural nature of many of the ARCHER images and the absence of road intersections or readily identifiable tie points in the imagery. All images were precision rectified and then subset so that only the imagery that covered the sites of interest was used. The preprocessing portion of this project took more time than was originally anticipated. The preprocessing steps were applied to 134 individual image segments of the over 190 that were acquired.

3.4.2 Data Processing:

ARCHER imagery was processed using one of two different approaches. The first approach, target detection, entailed collecting spectral signatures of materials of interest from scenes covering each study area. Those signatures were then used to identify additional sites where the material of interest had the potential to exist. The second approach, end member analysis, uses the spectrally over-determined nature of hyperspectral data to find the most spectrally pure (or spectrally unique) pixels (called endmembers) within the dataset.

Ideally, a spectral library of contaminated materials signatures obtained from spectrometer ground readings, such as an ASD Field Probe spectrometer, would have been created to identify contaminants using the target detection approach (Aspinall et al. 2002). However, a number of limiting factors did not allow for this. Instead, project managers and experts familiar with each target site helped to identify known contaminant locations on the imagery. Spectral signatures were then acquired from the imagery and used to create a spectral library for each study site. A Spectral Angle Mapper (SAM) classification routine was used to identify areas with similar spectral values, which may indicate that similarly contaminated materials are potentially located there. SAM compares the angle between the end member spectrum (considered as an n-dimensional vector, where n is the number of bands) and each pixel vector in n-dimensional space. Smaller angles represent closer matches to the reference spectrum. Those pixels with the smallest angle between the reference and image spectra are most likely to contain the contaminated material of interest. As material becomes less similar, the angle between the reference and image spectra increases.

The SAM classification was applied to only those sites in which detection of the target contaminant was considered feasible (Figure 8). However, the algorithm had to be applied individually to each image segment, which took a great deal of processing time. After the SAM classification was applied, analysts had to determine the angle at which potential contamination was most accurately detected, based on knowledge gleaned from meetings with contaminant experts (Figure 9). Again, this had to be performed on an image by image basis. After each image for a given site had been fully processed, all images could be displayed to highlight the detection of potential contamination over each given study area.

The end member analysis approach attempts to define the most spectrally pure (or spectrally unique) pixels within the data set and map their locations. This procedure was implemented using ENVI's Spectral Hourglass Wizard. This wizard streamlines the process of determining spectral endmembers from the hyperspectral imagery. The steps involved in the spectral hourglass wizard are outlined below.

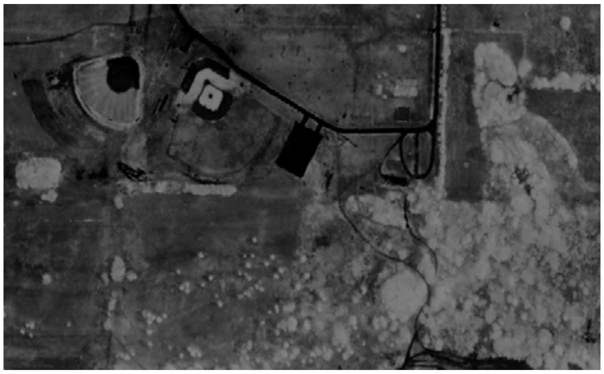


Figure 8 - Unthresholded SAM classification

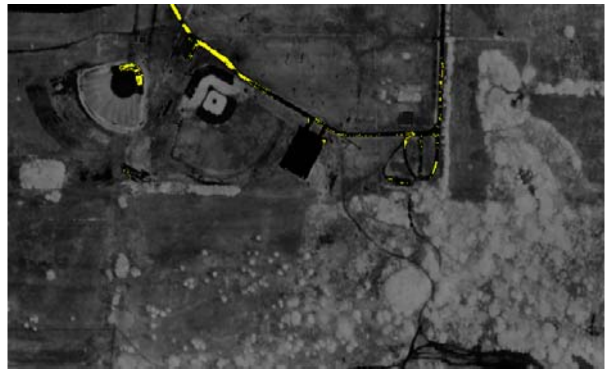


Figure 9 - Thresholded SAM classification

1. Input/Output file selection
2. Minimum Noise Fraction (MNF) Transformation to reduce spectral dimensions
3. Review of MNF results

The MNF transform is used to determine the inherent dimensionality of image data, to segregate noise in the data, and to reduce the computational requirements for subsequent processing. Some MNF bands contain data (Figure 10) while other MNF bands contain noise (Figure 11).

Figure 10 - MNF Band 1 Image

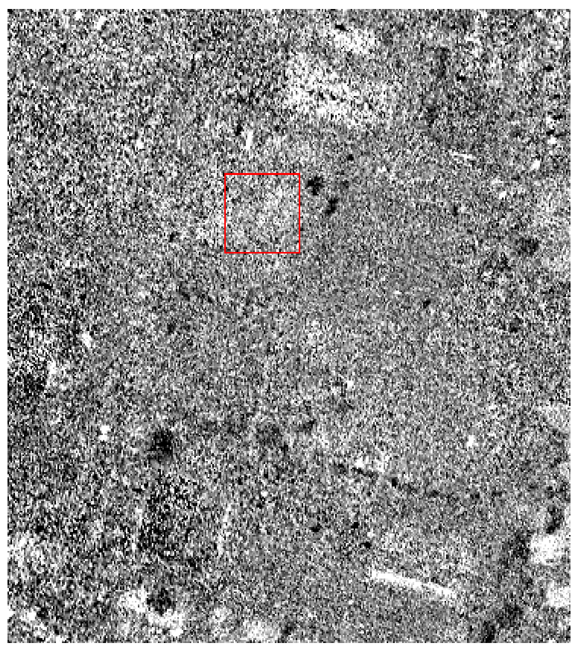


Figure 11 - MNF Band 15 Image

4. Data dimensionality determination
5. Pixel Purity Index (PPI) to reduce spatial dimensions
6. Review of PPI results
7. n-Dimensional visualization, including auto-clustering, to select and retrieve individual endmembers

The n-Dimensional Visualizer is used to locate, identify, and cluster the purest pixels and most extreme spectral responses in a data set (Figure 12). The colored points represent potential endmembers that are shown within the data cloud.

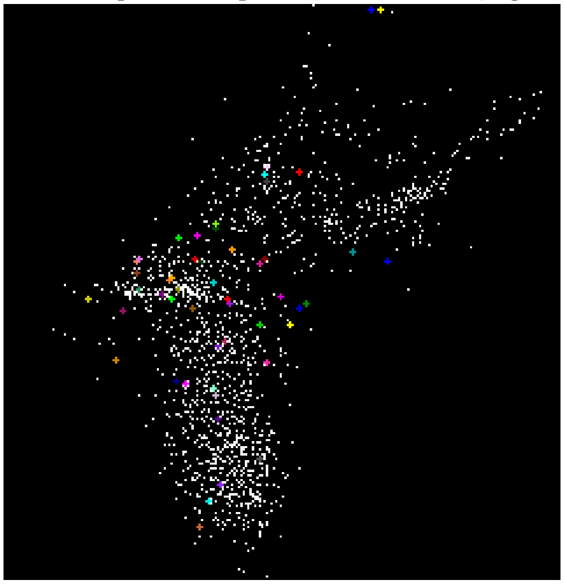


Figure 12 - n-Dimensional Visualizer

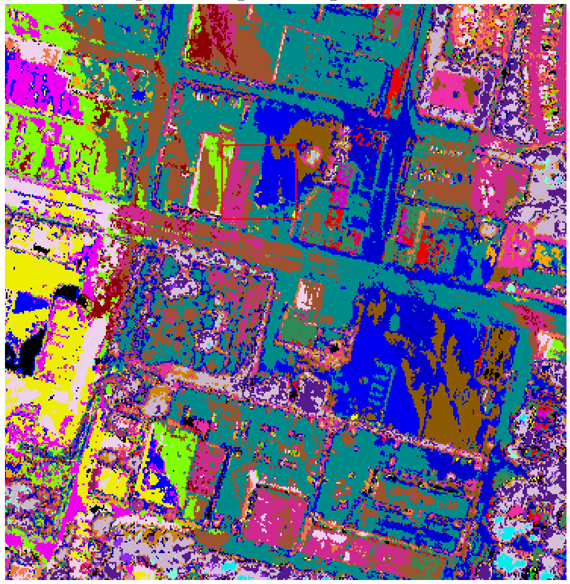


Figure 13 - SAM classification results

8. Spectral mapping using Spectral Angle Mapper (SAM) classification

The SAM classifier compares the angle between the endmember spectrum (developed above) and each pixel vector in n-dimensional space. The smaller the angle between the two spectra, the closer the pixel spectra matches the reference spectra.

9. Investigation of mapping results

The classification results are examined to determine if the patterns present correspond to know conditions on the ground (Figure 13).

3.4.3 Analytical Results:

HSI was collected on 14 sites in three flights from Jefferson City. Attachment 4 provides an overview of the collection sites. Transit times and sun angle parameters precluded collection against all pre-planned sites. Collection was planned against a diverse set of contamination conditions with the intent of conducting a preliminary assessment of conditions with the highest potential for success. Those that were most promising were then analyzed in greater detail. Attachment 5 provides imagery and graphic analysis, where conducted, of the sites described below. Clips of the imagery are included with the discussions. The strips and one-minute segments of imagery were stitched together for an overall low-resolution view of the site for this report. The imagery and associated data has been archived by UMC, and can be used for additional analysis. Due to time and funding limitations, not all sites were analyzed.

3.4.3.1 Granby, Aurora and Wentworth Lead Mining

These southwest Missouri cities are in the Tri-State Mining District. They are part of a state and federal project to assess the extent of lead contamination in residential areas and to locate abandoned mining activity and waste. Dave Mosby and Rebecca Wells-Albers, Sep 22, and Karen Cass, Oct 20, Superfund Section, reviewed the imagery at UMC. They identified an area in Baldwin Park, Aurora,

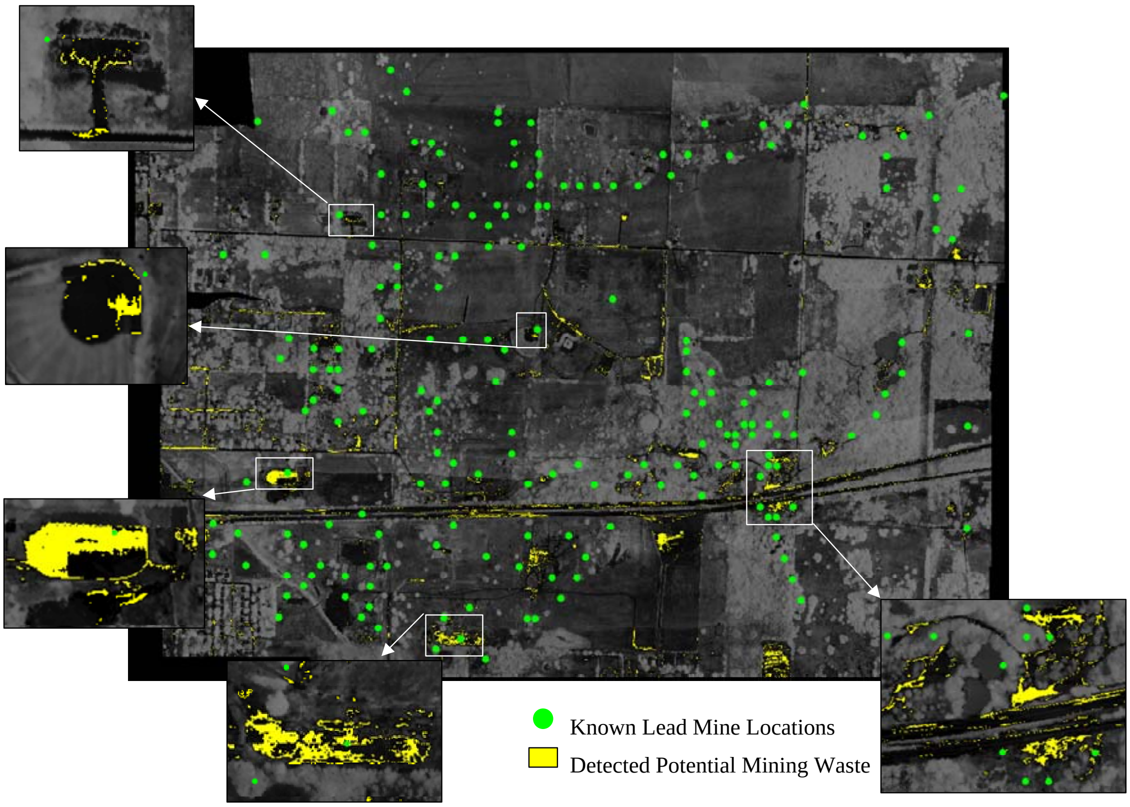


Figure 14 - Aurora Analyzed Imagery

where high concentrations of Zinc tailings/waste from lead mining had been documented. Dr. Blodgett developed a spectral signature from that area. The signature was then processed in IMAGINE for imagery of all three cities. The Attachment 5 shows the imagery of each city in false color (brightness of red indicating health of vegetation) and the imagery with the processed signature (yellow are locations of the same signature with closest correlation to the original Baldwin Park signature). Since these were large areas, 2-3 km square, they were flown in a racetrack-like pattern with successive passes flown in the opposite direction. This caused some differences in the signature, which UMC had to compensate for. The Aurora example, Figure 14, shows the imagery in black and white with areas that matched the Baldwin Park signature in yellow. The lower right-hand corner insert is the area in Baldwin Park where the signature was developed. Overlaid on the imagery are the locations of lead mines, taken from the departments mine inventory database. Many of the identified areas are near known mine sites. Vegetation is a limiting factor in this type of analysis. The signature only applies to bare ground. Most of the area is covered with vegetation. Certain contaminants do have an effect on vegetation, and HSI can be used in some situations to detect vegetation stress. Zinc in high concentrations inhibits vegetation growth. Zinc is a major component in the mine waste in SW Missouri. Therefore, more areas were detected by this process in these three areas than in Washington

County, where the mine waste has not had as great an impact on vegetation. The effects of mine waste on vegetation should be addressed in a separate study. Additionally, these apparent detections have not been verified by follow-on ground truth data collection. Follow-on ground truth analysis has been proposed to verify the initial results.

3.4.3.2 Big River North of Bonne Terre

The Big River is contaminated with metals, primarily lead, from mining in the area and the use of the mine tailings for dams. Several sediment and sampling studies have been done along the river. Two conditions were of interest, high levels of lead contamination along the river, and areas in the imagery where tailings or mine waste were used for roads and other construction. Bob Hinkson, Superfund Section PM, reviewed the imagery, Figure 15, and identified sandbars and flood plain areas where mining materials were known to have been deposited and lead had been detected. Several signatures were developed and applied to the remaining imagery. Several areas along the riverbanks, road shoulders, housing areas, and other locations were highlighted. Some sand bars matched known or suspected contaminated locations. Because of time constraints and funding limitations, graphics of the contaminated areas were not produced, and the data was not used for ground truth. However, it appeared that the process was producing information that could be used to direct PMs to areas with higher potential for contamination than could be obtained through visual inspection and sampling. Many areas are not easily accessible, so this type cueing to focus assessment would be important.

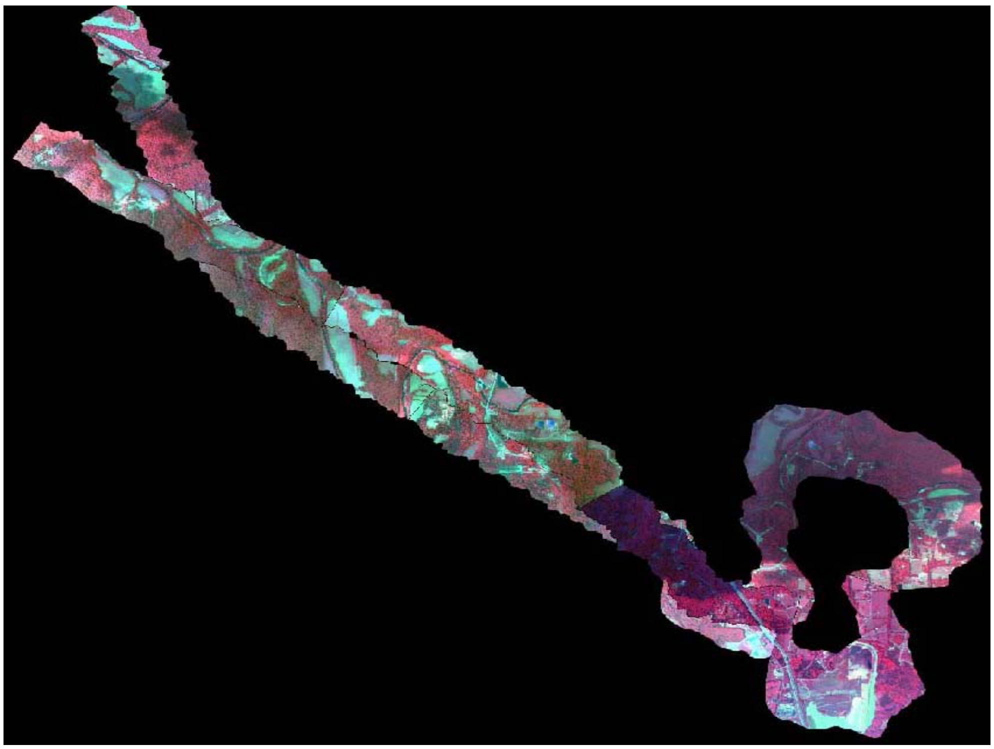


Figure 15 - Big River Sediment Study

3.4.3.3 Flood Borne Contamination at former HCI Chemical, and National Imagery and Mapping Agency (NIMA)

The 1993 flood inundated many waterfront industrial sites along the Missouri and Mississippi rivers. Several closely located sites were chosen for collection, and included the National Lead paint pigment plant, Carondelet Coke coal conversion plant, and the National Imagery and Mapping Agency, later renamed the National Geospatial-Intelligence Agency (NGA), which processed imagery and recovered silver, Figure 16. The flood washed a mixture of contaminants down the river and may have

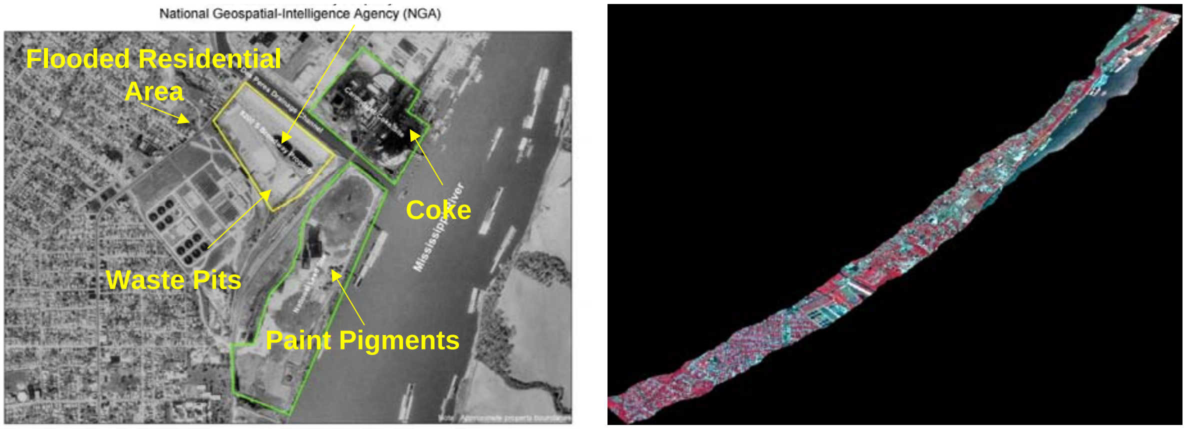


Figure 16 - Flood borne Contamination Mississippi River

deposited some of those in a flooded residential area above the facilities. The objective of this collection was to determine if the signature of the flooded plants/facilities could be detected in the residential area. If feasible, the capability would allow Emergency Response personnel to identify areas of flood borne contamination. Time lapse since the flood would have diluted the signature, but may have left an identifiable change in the flooded residential area. Because of time constraints and funding limitations, this site was not analyzed.

3.4.3.4 Hematite Radiological Contamination

The former ABB Combustion Engineering site, now owned by Westinghouse Electric Company LLC (WEC), is located northeast of Hematite in Jefferson County. The facility manufactured nuclear fuel for defense and commercial power plants until 2001. Parts of the 228-acre site have been impacted by radiological and chemical contamination, and groundwater under nearby private properties has been impacted by industrial solvent contamination originating at the site. The conditions of interest for the Pilot Project were seeps from waste pits, a settling pond and a spring/shallow run-off pond into a nearby creek, location of waste burial areas around the plant and vegetation stress in the surrounding area from contaminated dust and other airborne derbies generated by the plant. Ben Moore, Federal Facilities Section PM, reviewed the imagery Sep 20 and identified runoff and settling ponds, which were used to a develop a signature. The signatures produced several potential seep locations along the creek. UMC also ran a Spectral Angle Mapper), end-member analysis described in 3.4.2. paragraph 8 above. Figure 17 is a

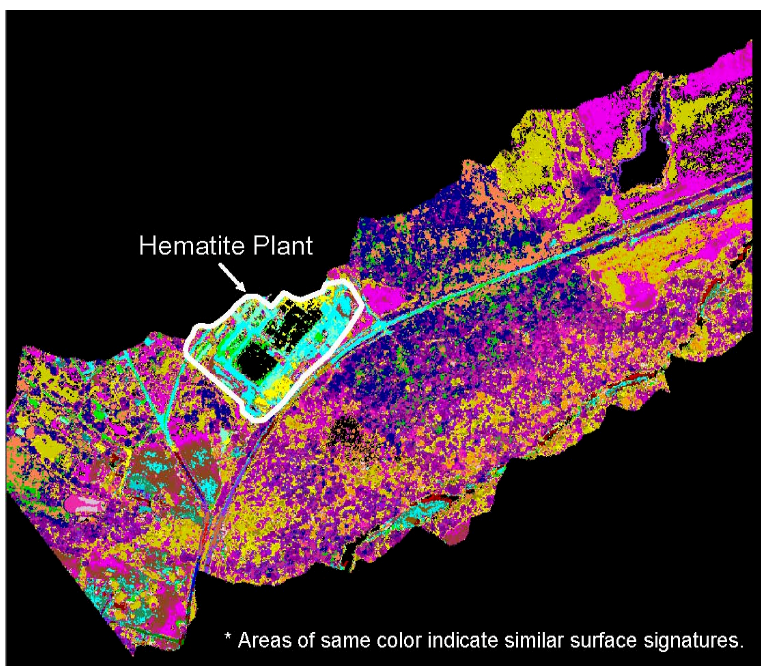


Figure 17 - Hematite Spectral Angle Mapper Analysis

clip of the results. A signature similar to the plant area shows up along the creek south of the plant. Because of time constraints and funding limitations, no further analysis or ground truth collection was accomplished.

3.4.3.5 Herculaneum Residential Lead Contamination

The Doe Run Smelter, Herculaneum, MO, is the largest active lead smelter in the country. It has been operating for over 100 years with lead releases to air and water that have contributed to elevated lead levels in the surrounding environment. Although steps have been taken to eliminate releases, some still occur into the air. Imagery was collected of the site for possible analysis of the impacts of airborne lead on vegetation, and the potential to determine the extent of contamination using vegetation stress. Figure 18 is a clip of the Herculaneum plant, which is located along the Mississippi River. There is a large pile of slag southwest of the plant that can be clearly seen in the picture. The housing area west of the plant was heavily impacted by lead dust. Because of time constraints and funding limitations, no further analysis was accomplished.

Figure 18 - Herculaneum Smelter

3.4.3.6 JZ & Bueneman Landfills

The JZ & Bueneman landfills, located north of Wright City, MO, had two conditions of interest to the project; seeps of leachate along the adjoining creek and vegetation stress from landfill methane. Mike Potter, Dept Inspector, reviewed the imagery September 14, and identified a leachate pond and associated wetlands that were constructed adjacent to a demolition landfill to drain leachate away from the landfill and creek. The imagery was processed using the leachate pond signature, and several locations along the creek were identified. Two creek locations matched those identified in a previous study of landfill seeps. Figure 19 shows the locations of the ponds used for the signature and locations along the creek with similar signatures. A large surface seep on the eastern edge of the landfill boundary had been covered, but may have reappeared. UMC provided coordinates for several of the potential leachate seeps for possible follow-on sampling in conjunction

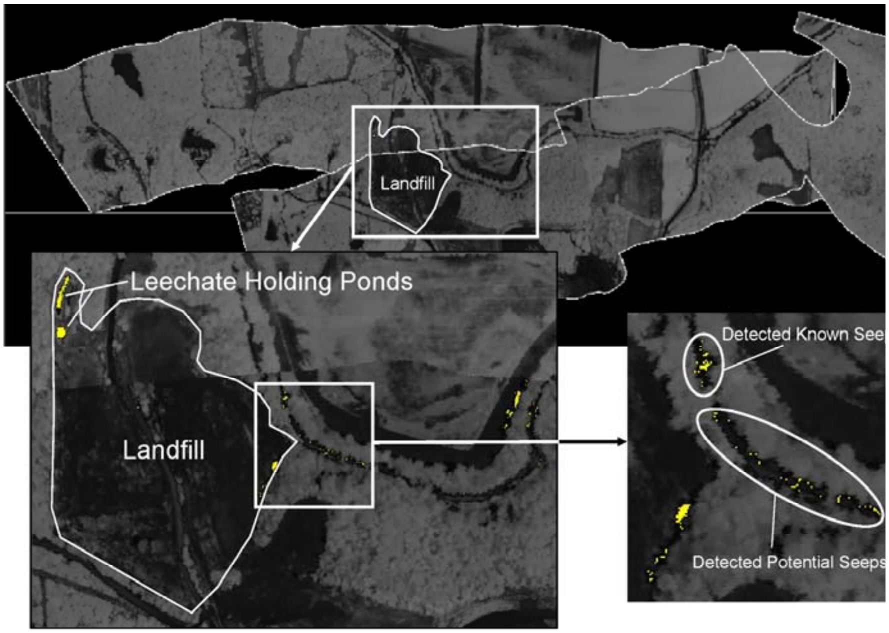


Figure 19 - JZ Landfill Seeps

with other department work at the site. As of this publishing, the sampling events had not yet been conducted.

3.4.3.7 Mineral Point and Potosi Areas Lead Mining

Mineral Point and Potosi are part of the old lead belt in eastern Missouri, one of three mining areas in the southern part of the state. Both cities are contaminated with a variety of metals from mining, lead being of primary concern. Dust from haul roads and mine tailings are spread throughout the area. An extensive lead sampling study of residential and contamination source areas is on-going, and levels affecting human health, in excess of 400 parts per million, have been found. The objective of the Pilot Project was to assess the ability of HSI to identify soils with high levels of lead, locate the dispersal of mine tailings and related waste, and highlight abandoned haul roads. Superfund PM, Jonathan Garoutte, reviewed imagery of Potosi on September 15, and identified areas that were found to have high lead levels during the on-going study, including a source area where tailing and mining waste had been piled. UMC developed a signature from a road through the source area, and applied the signature to Potosi and Mineral Point. The process highlighted residential areas that had not been sampled, a parking area around a new mall in Potosi, segments of roads and other areas. Figure 20 is a clip from Attachment 5 showing the area coverage of Potosi with locations with the source signature in yellow. As mentioned in the paragraph on Aurora, the process can only identify locations where there is no vegetation. Much of the residential contamination resulted from years of dust from ore trucks that settled on the grass covered yards. Grass is less affected by the mineral composition of the ore in the old lead belt than the Tri-State Mining District where there are high concentrations of zinc that inhibit plant growth. Jonathan checked one site, a concrete parking area, with a field-portable x-ray fluorescence (FPXRF) and got a high lead reading. It appears that mine tailings were used as aggregate in concrete.

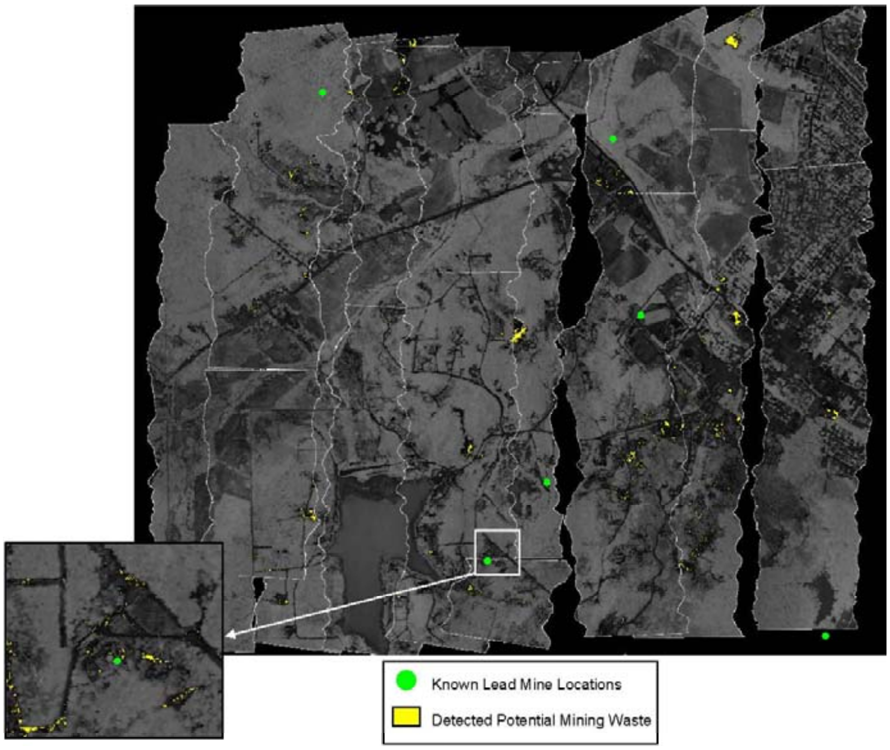


Figure 20 - Potosi Lead Contamination Analysis

ARCHER normally flies at 2500 ft above ground for one-meter resolution imagery. One pass at a lower altitude of Potosi was planned for the project to assess whether higher resolution would allow greater determination of the levels of contamination. The objective was to determine if higher resolution imagery, 60 cm was obtained, would help distinguish between low and high concentrations of contaminants, e.g., between 400 and 4000 ppm lead.

Figure 21 - Potosi Low Altitude Collection/Concentration Level Analysis

Figure 21, left side, is a clip of the single low altitude pass along hwy 185 in Potosi. The full image and initial analysis are at Attachment 6. Figure 21, right side, is a clip of detailed analysis of the Potosi fairgrounds. Instead of the single yellow color used in other analyses, highlighting the closest correlated signatures, a range of colors was used to show the gradual widening of the angle of correlation between exact and no correlation. Red shows areas that are the closest match to the signature developed from the source identified by Jonathan, with yellow, green, cyan and purple showing areas that were progressively further from a matching signature. Additional graphics of Potosi and the concentration range analysis are provided at Attachment 6.

On November 17, Shawn Muenks and Nick Carbone, Federal Facilities Section, took the imagery of Potosi, both low and high altitude range of correlation images, Attachment 6, and an FPXRF to collect readings of surface metals in the source area identified by Jonathan, and the areas analyzed by UMC. UMC also provided coordinates for red, yellow, cyan and purple areas for ground truth collection. Unfortunately, some of the areas were not accessible or had changed due to construction since the August flight. Figure 22 is the fairgrounds at the intersection of highways 185 and 8. The left clip is the imagery analysis, and the right clip, Attachment 6, is the results of FPXRF sampling.

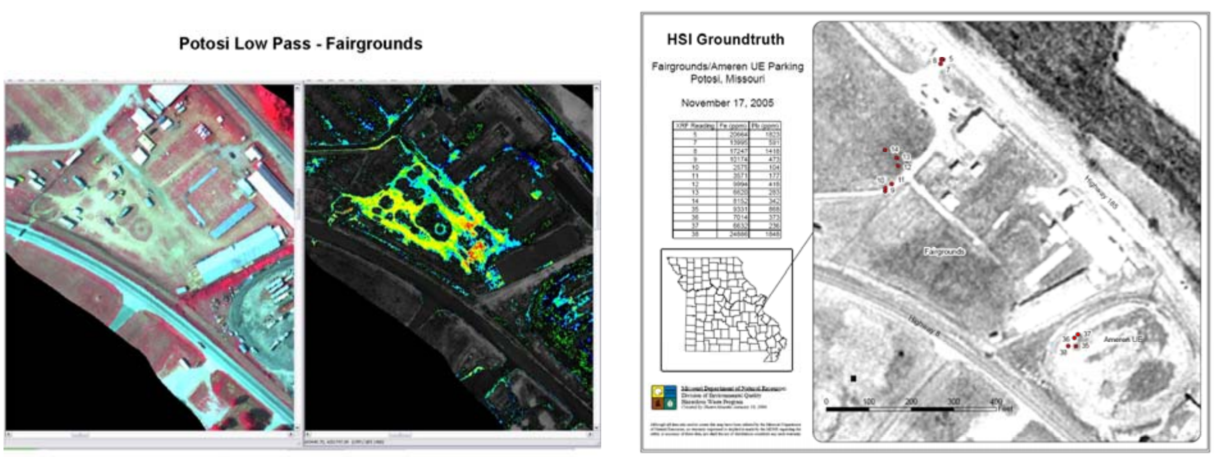


Figure 22 - Potosi Low Altitude Collection/Ground Truth Data Collection

The main fairgrounds area, where UMC had provided coordinates, was not accessible. FPXRF readings were then taken from either side of the fairgrounds, the fairgrounds parking and an Ameren UE equipment storage area, using land features and color coding from the graphics to locate various concentration levels. The right clip, Figure 22, shows the readings for iron (Fe) and lead (Pb) in parts per million (ppm). Most of the areas that should have been high in lead were not above 1000 ppm as expected, although the paved entrance to the fairgrounds parking was 1400 and 1800 ppm, probably from the use of tailings for aggregate. However, we did record high iron readings, in access of 10,000 ppm. An iron level of 23,000 ppm or above is of concern. Subsequent collection at the source, Attachment 6 titled Housing and Source Area and High School and Housing Area, also provided readings that were low in lead and high in iron. This may indicate that, even though the source area was a lead mining waste pile, the surface of the area was not reflective of the buried waste. The results further emphasized the need to collect spectrometer readings of the contaminated areas of interest, preferably at the same time as the airborne collection, so that areas used as the basis for the signature is reflective of the contamination of interest.

3.4.3.8 Praxair Inc. Downtown St. Louis Asbestos Dispersal.

The Praxair tank farm fire provided an opportunity for ad hoc collection against an Environmental Emergency Response (EER) related site. Many of the compressed gas tanks that exploded contained

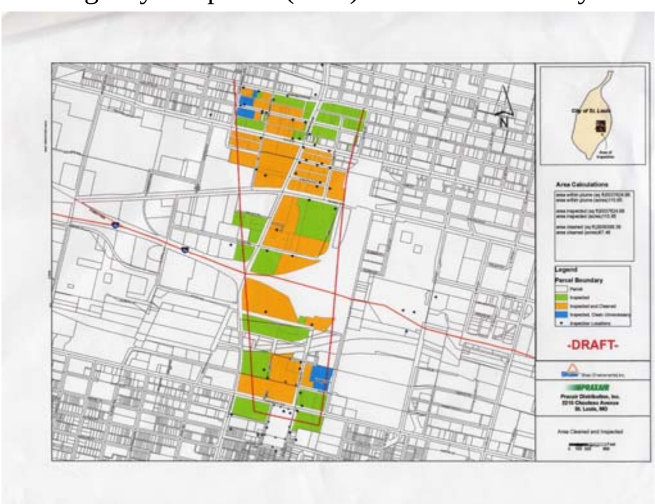


Figure 23 - Praxair ASPECT Plume Diagram

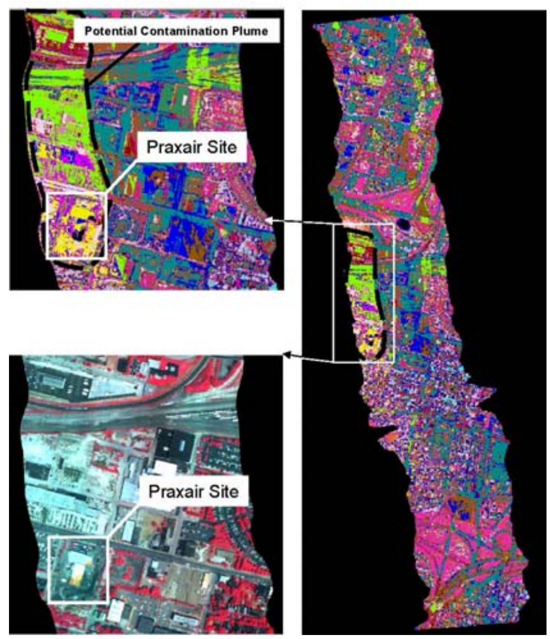
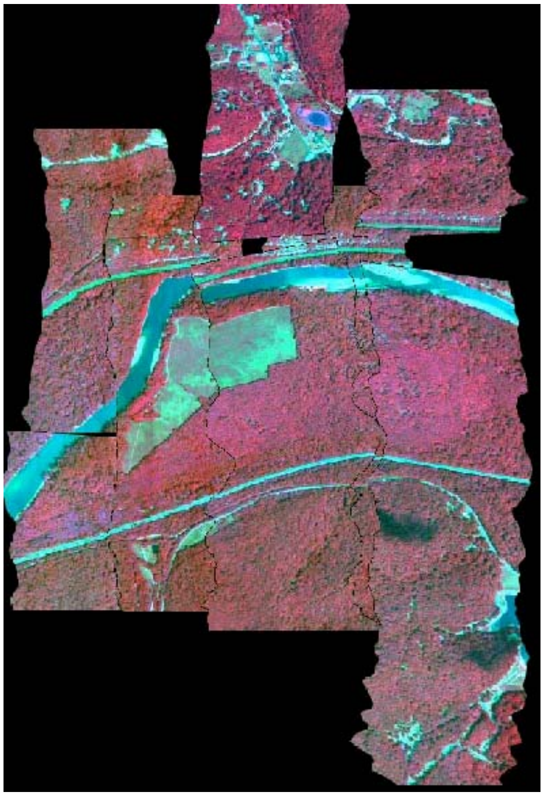


Figure 24 - Praxair Endmember Analysis

asbestos. EPA's ASPECT aircraft tracked the plume of chemicals from the fire, and the aircrew provided EER personnel a plot of the area covered by the plume, Figure 23. The ARCHER HSI was collected 45 days later with the objective of assessing the sensor's ability to determine the extent of asbestos dispersal. By the time ARCHER flew, much of the asbestos had already been cleaned up in the area plotted by ASPECT. UMC conducted a preliminary analysis of the affected area using an endmember classification routine. Figure 24 shows the results of the endmember analysis. The classification identified areas within the known contaminated area that matched the predominant signature from the tank farm. It also identified areas outside the search area. John Whitaker, EER, reviewed the Praxair imagery on September 29. Due to the progress of the cleanup, no sampling or further ground truth efforts were undertaken. However, the process does indicate a potential application of HSI for this type EER response to chemical fires, particularly if conducted in conjunction with EPA's ASPECT real-time support.

3.4.3.9 Tyson Valley Powder Farm Contamination Plume.



Branden Doster, Federal Facilities Section, reviewed the imagery September 28. The Army in conjunction with the St. Louis Ordnance Plant used this site for storage, of powder, pyrotechnics and incendiary chemicals, and for testing of small arms ammunition. The storage area is on a bluff overlooking a river and flood plain. Solvents and other contaminants were dumped in pits on the site, and have subsequently migrated down to the flood plain area below. Monitoring wells and other sampling have defined a contamination plume. The objective of HSI collection for this site was to evaluate the potential use of vegetation stress as an indicator of groundwater contamination. Department personnel experienced with contamination uptake in vegetation advised that uptake varies by vegetation and contamination type, and that a survey of the area would be needed to ensure that the right type vegetation was in the area to provide a detectable signature. A signature of the contaminant pits would also be used to locate potential seeps in the river. Because of time constraints and funding limitations, analysis was not attempted.

Figure 25 - Tyson Valley Vegetation Stress

3.4.3.10 Weldon Spring Site Remedial Action Project (WSSRAP) Radiological Contamination.

The Atomic Energy Commission (AEC) built and operated the Weldon Spring Uranium Feed Materials Plant (Chemical Plant) on 200 acres of the WSSRAP site, processing uranium ore, small amounts of thorium, and other radioactive materials. The ARCHER aircraft made a single pass through the area to collect a swath from a contaminated spring to the end of a drainage area where it emptied into the Missouri river. Surface contamination at the site has been remediated. However, some ground water contains low levels of contamination, which is occasionally detected in springs in the surrounding area. Ben Moore, FFS, reviewed the imagery on September 20. The objective was to use the known contaminated spring to identify additional contaminated springs and determine if contamination was entering the Missouri from the drainage area. Unfortunately, the coverage did not include the portion of the drainage at the Missouri river, and the tree canopy precluded clear views of many of the springs. No further analysis was attempted.

Figure 26 - WSSRAP Radiological Contamination

3.4.3.11 Bear Creek Quarry Tire Dump

The Bear Creek Quarry contained a tire dump, white area in the center of Figure 27, which caught fire recently. Most of the tires were destroyed. The Quarry was on the transit path for ARCHER. Imagery was collected to determine if HSI would detect the black tires, which would normally absorb light and provide no signature. The are many illegal tire dumps in the state, and the department is evaluating options for locating the dumps in relatively secluded areas. Kirk Mitchell, Solid Waste Management Program, reviewed the imagery on the ARCHER ground station. Some tires were observed, but were not recognized by the sensors match filter when the imagery was played back through the ground station. It is possible that ARCHER's anomaly detection algorithm might detect illegal trash dumps, which contain a variety of waste material and would stand out as anomalies against vegetation background. Further evaluation would be required and could be attempted during transits for collection against designated sites.

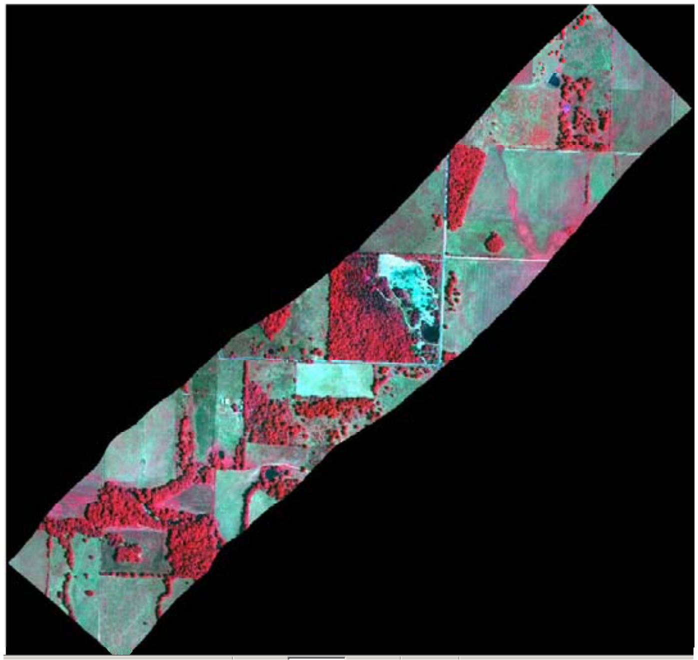


Figure 27 - Bear Creek Quarry Tire Dump

3.4.3.12 Capitol and DNR buildings

Attachment 5 contains images of the Missouri Capitol and surrounding area, and the Department of Natural Resources, Lewis & Clark State Office Building, Figure 28, taken during ARCHER's return transit to the Jefferson City airport.

Figure 28 - Missouri Department of Natural Resources' Lewis and Clark State Office Building

3.4.4 Contamination Signatures:

Spectral signatures from areas of known contamination were used to identify other areas with similar spectral characteristics that may also have the potential to be contaminated. Spectral signatures were acquired directly from the ARCHER imagery. Because light conditions, background material, and the mineral compositions are different for each site, spectral signatures must be collected and applied to that particular site for the most accurate results. The signatures for one site can not always be applied to other sites with similar contaminants or even to the same site at a later date due to the many environmental variables that change over time. For example, lead tailings in Newton and Lawrence counties in Missouri do not have the same signature as lead tailings in Washington County, Missouri. (Figure 28 is a Washington County lead signature.) Thus, the creation of a spectral library of contaminants to be used with ARCHER would have limitations. Attachment 7 provides two examples of spectral signatures.

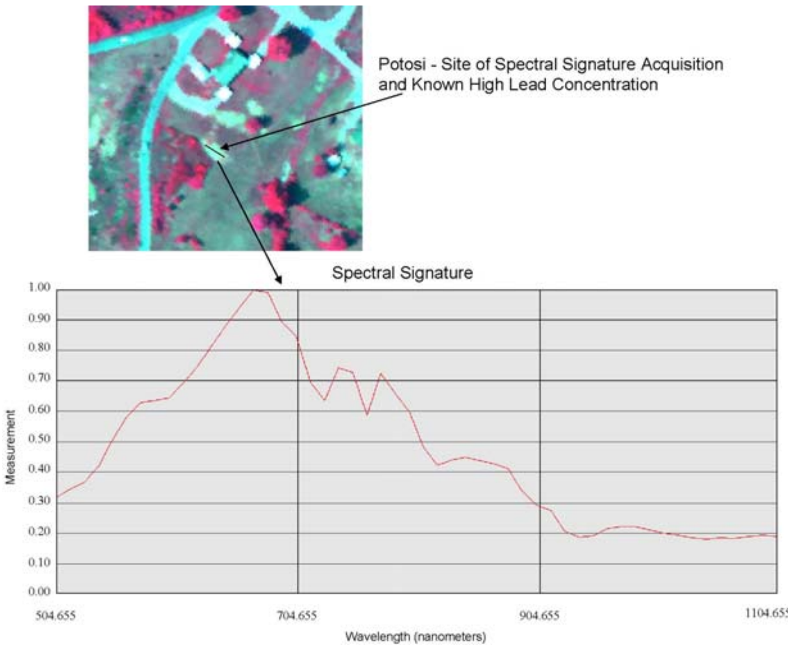


Figure 29 - Spectral Signature of Lead Contaminated Area

3.4.5 Imagery for Other Agencies:

The Project offered to provide imagery to other state and federal agencies, during the April, 2005 Workshop and through personal contact. Two agencies requested imagery.

U.S. Geological Survey. Mr. Jim Felkerson, USGS, conducted a study of oak decline in southeast Missouri, focusing on the Potosi and Salem Ranger Districts. The study used HSI from a commercial sensor to evaluate spectral response as a tool to measure pre-stress indicators in oak trees. However, more data, with better resolution, was needed to continue the study. This Project was scheduled to collect HSI of one USGS area during the return transit from Potosi. Unfortunately, the daylight collection window closed before the imagery could be collected.

Missouri Department of Conservation. Mr. Chris Wieberg, MDC, is evaluating the use of HSI to differentiate between grassland types. Dr. Blodgett provided sample data. The evaluation had not been conducted in time to be included in this report .

Imagery may still be obtained by state and federal agencies through the department.

4. RECOMMENDATIONS AND LESSONS LEARNED

4.1 CAP ARCHER Mission Planning And Collection

4.1.1. Tasking.

ARCHER support is requested through the CAP National Operations Center (CAPNOC) at http://level2.cap.gov/index.cfm?nodeID=5264. CAP performs Air Force Assigned missions, primarily for State and Federal Emergency Management Agencies (SEMA & FEMA), as part of their emergency response mission. Those missions are established under a Memorandum of Understanding (MOU) in which the Air Force funds the mission and provides Federal Employees Compensation Act (FECA) coverage for CAP volunteers. ARCHER has several existing capabilities to support disaster relief/search and rescue, and the crews are trained to implement those capabilities in the air and on their ground station. ARCHER will be available around the country and should be requested for emergency response/disaster relief. Applications and response times should improve as aircraft are deployed and crews are trained.

CAP also performs corporate missions that do not meet the criteria for Air Force Assigned Mission (AFAM) status, but do fall under one of the corporate objectives. ARCHER support to this Pilot Project was performed as a corporate mission, and expenses were reimbursed by the Project. State and federal agencies interested in using ARCHER and CAP's existing capabilities may need separate MOU's for non-AFAM missions in order to reimburse expenses and provide Worker's Compensation coverage for crews. Several states and federal agencies have developed non-AFAM MOUs.

4.1.2. Deployment.

The ARCHER aircraft deployed to Jefferson City, MO, with one pilot and all required equipment, including the ground station, in the aircraft. One additional pilot and two aircrew members arrived separately. The aircraft can operate out of almost any airfield, but must have hanger space to protect the aircraft and equipment. It is best to base ARCHER as close to the collection area as possible to minimize transit time. Lighting conditions are optimal for only about four hours daily. The cramped conditions will fatigue the crew. A good schedule would be two hours in the morning, land for a lunch break, and two hours in the afternoon.

4.1.3. Mission Planning.

To optimize non-emergency missions, the crew needs planning materials in advance or upon arrival. Aerial photography of each site with the corners or flight path annotated with coordinates provides a good visual orientation. Figure 29 is a planning graphic for the Tyson Valley site. Attachment 4 graphics were used in plotter size on the wall for display and briefing. Coordinates for corners of area targets or ends of the flight path should also be provided in hardcopy and an electronic file. The equipment operators must load all the coordinates in ARCHER TRAC to ensure complete coverage of the area. The pilots use the plot of sites to develop a flight plan. The planning

Figure 29 - Mission Planning Graphics

process can be time consuming, and could impact collection if the right materials are not available. Communicate with CAP and provide planning materials in advance.

4.1.4. Improvements to ARCHER data delivery.

For ARCHER imagery to be used by personnel outside of CAP, the data must be delivered in a format that is more user friendly (see paragraph 3.4.1.). This would include elimination of the effects of aircraft roll, pitch, and yaw, processing of segments into a "North up" orientation, and output in a universal raster data format such as GEOTIFF. Additional improvements to the delivered data that would enhance it's usefulness would include, production of site specific mosaics, pan sharpening of the hyperspectral data, the use of differentially corrected GPS data in the geocoding process, and the use of a compression algorithm to reduce file sizes. These improvements to data delivery will minimize the time required for data preprocessing and therefore maximize the time available for analysis.

4.1.5. Improvements to ARCHER data collection.

Two improvements to the ARCHER data collection process would greatly enhance its' usability. The first would be the ability to include GIS data layers during mission planning, data acquisition, and ground station processing of the imagery. This would allow for quick identification of site boundaries (e.g., Aurora) or points of interest (e.g., State capital building). It would also allow for the identification of which image segments fall within your study area. This would minimize the time required cataloging data. The second improvement would be to the ARCHER TRAC system or to increase the amount of overlap used in adjacent segments. During the deployment of ARCHER in Missouri, ARCHER TRAC showed complete coverage for all sites of interest. However, upon processing, gaps in data coverage were revealed for many site locations, leaving holes in the imagery. Either improvements to the ARCHER TRAC or an increase in overlap would alleviate this problem.

4.1.6. Ground Truth.

The following is a recommended sequence of planning & collection.

<u>Site Visit</u>:

- Conduct a site visit with the PM before the mission to locate areas of interest that do not have vegetation. Take XRF or other field readings to confirm high levels of the contaminant of interest. Collect coordinates.
- If vegetation stress will be the analytical key, then locate types of vegetation that uptake the contaminant of interest, in a known contaminated or impacted area. Collect coordinates.
- Locate several reference points for georeference check of the imagery, and collect coordinates.

<u>Collection</u>:

- Collect the imagery and spectrometer data concurrently. The spectrometer data should be collected of the area identified in the site visit.
- Place a cloth panel or other marking near the known location and collect coordinates.

<u>Re-Visit</u>:

- Generate coordinates for a selection of locations identified with the same or similar signature as the source. IMAGINE and ENVI can output a file of all identified areas.
- Revisit the site and collect field screening readings of the potentially contaminated areas. Collect readings of areas in similar condition, e.g., exposed ground or similar vegetation that did

not show similarities to the source during analysis to determine if the processing is missing contamination. Collect coordinates.

4.2 HSI Environmental Applications

4.2.1. Environmental Emergency Response.

ARCHER has a build-in automated Anomaly Detection capability. That should make it useful during and after a flood for locating flood borne objects, such as propane tanks, drums of potential hazardous materials and other items of interest. It also has a Spectral Signature Matching filter, which is similar to the signature analysis process used by UMC. A known signature is used by the filter to look for matching objects or locations. (See the Project web site, paragraph 2.3, for the ARCHER capabilities brief.)

The analytical processes used by UMC, and to a degree the ARCHER match filter, have the potential to identify deposits of some contaminants left behind in flooded areas. Sections of the Big River in Missouri's Old Mining District have deposits of mine tailings left behind after a tailings dam was breached. A preliminary review of ARCHER imagery of a small portion of the Big River, using a tailings pile for a signature, showed locations along the river where tailings may have been deposited. Since some of these areas may not be easily accessible, HSI coverage of the flooded area may provide EER personnel with an initial indication of where the most contaminated spots may be.

Although not flown concurrently, the ASPECT and ARCHER coverage of the St. Louis Praxair fire show complementary roles for the two HSI systems in tracking the plume and locating the resultant contamination fallout. Emergency response is a CAP mission, which may fall under the Air Force funded and supported category. Even without follow-on analysis beyond the ARCHER ground station, states and federal agencies should use ARCHER for major EER responses to evolve the process and the applications.

4.2.2. Contamination Characterization.

The Project collected HSI for a preliminary assessment of the ARCHER sensor's ability to characterize contamination using several different indicators. The indicators included: vegetation stress, similar to the way crop health provides a visible indicator of soil nutrients; using a contaminant at a know location to identify other contaminated areas, such as locating mine tailing deposits or abandoned mine activity; evaluating the degree of contamination, and identifying differences or anomalies, such as seeps along a creek or illegal trash dumps.

4.2.2.1 Vegetation Stress.

The Project did not attempt to evaluate vegetation stress as an indicator of contamination. However, several areas were imaged where buried hazardous waste or contaminated groundwater is an issue. The Hematite Radioactive site has waste pits on the plant grounds, which were not well documented and have not all been accurately located. Tyson Valley Power Farm and the Weldon Spring Site have contaminated ground water plumes that have been generally located, but could be more extensive. JZ & Bueneman Landfills, like many landfills, have a methane plume that may not be completely defined. A study of the landfill showed a noticeable effect on softwood tress from the methane. Airborne emissions from the lead smelter at Herculaneum have deposited contaminants on vegetation in the area. In addition, identifying mining contamination through vegetation stress would be a significant capability, particularly in residential areas where the dust from transporting ore has mixed with ground cover.

Some of the research in Phase I located studies and projects that evaluated HSI for detecting vegetation stress. The paper on Species Identification and Stress Detection of Heavy-Metal Contaminated Trees, Attachment 1, used a sensor similar to ARCHER to show the extent of zinc contamination from a former zinc-melting factory in Belgium, through analysis of stress in pine trees. This process may be applicable to the lead mining areas in southwest Missouri where there are high concentrations of zinc. However, vegetation stress is dependent on the type of vegetation and the contamination. Grass has been an effective cover for some lead-contaminated yards, and may not have detectable differences from other yards. Our staff experience is that grasses and sedges are two forms of vegetation that do not uptake contamination. Broad-leafed weeds around the residential areas may be more of an indicator. Staff experience is that Wild Mustard, found in Missouri in the spring, and Sunflower, found in early summer, do uptake lead. Research needs to be done on the specific contaminant and vegetation before using stress as the only indicator.

4.2.2.2 Known Contamination.

The Project's greatest success was using known contaminated surface conditions, selected by the Project Managers from the imagery, to identify other areas with similar conditions. Only limited ground truth was feasible. The Potosi ground truth initiative, described in 3.4.3.7, is the only recorded ground truth data, and it showed that the surface signature may not be reflective of the sub-surface contamination. The area used for the lead signature was a mine waste area, but the surface area was relatively low in lead. The key is choosing the right surface area and, if possible, obtaining a ground spectrometer reading before and concurrent with the flight. The signature can be used by ARCHER's match filter.

Some ground truth initiatives are scheduled as part of follow-on projects, so the results remain largely exploratory. However, the contaminated areas identified in several mine waste areas, based on dialog between the PMs and UMC analysts, appear to the PMs to be consistent with fieldwork. The JZ & Bueneman landfills, 3.4.3.6, is another example of the PM providing the analyst with background on the layout of the site and the results of a study, which addressed leachate seeps and methane releases, that enabled the analyst to pick a leachate pond as the source for a spectral signature. The results were the identification of know and additional seeps in the surrounding area and in an adjoining creek. PM participation with the analysts is a key to improving results.

4.2.2.3 Degree of contamination.

The low altitude collection in Potosi, 3.4.3.7, was attempted to assess the capability of HSI to determine the degree of contamination. The variation in colors represented the increasing angle or degree of difference between exact signature match and no match. The objective was to measure the accumulation of dust from lead ore along haul roads. The dust should have been greater adjacent to the haul roads, decreasing in concentration with the distance from the road. Unfortunately, the dust was mixed with a variety of soil types, each with its own signature. The results were inconclusive. This may have been the wrong contamination and condition for this evaluation. Further ground truth collection would be required to provide a better assessment. Follow-on tasks may attempt to evaluate the degree of contamination using other conditions and contaminants.

4.2.2.4 Contamination anomalies.

ARCHER has an anomaly detection capability, which may be suitable for locating illegal trash and tire dumps, petroleum and solvent pits, and other contaminants and conditions that are different from the surrounding area. CAP personnel ran the anomaly detection function during download of the imagery from the aircraft to the ground station. Homes, automobiles and similar objects provided frequent alerts in rural areas. The system has the capability of identifying an object in heavy tree cover if there is a one square meter opening in the trees. This capability was not evaluated for solid waste or contamination detection, but should be if ARCHER is used in rural areas. The sensor can be left on during transits with the sensor operator flagging only those areas of interest for retention.

ATTACHMENT 1 - MSI/HSI ENVIRONMENTAL PROJECT RESEARCH CONTACTS & PAPERS

ATTACHMENT 2 - OSWER PILOT PROJECT WORKSHOP REPORT

ATTACHMENT 3 - DEPARTMENT REQUEST FOR ARCHER SUPPORT

ATTACHMENT 4 - ARCHER MISSION PLANNING MATERIALS

ATTACHMENT 5 - SITE COLLECTION AND ANALYSIS

ATTACHMENT 6 - POTOSI LOW ALTITUDE COLLECTION AND GROUND TRUTH

ATTACHMENT 7 - SPECTRAL SIGNATURES

ATTACHMENT 8 - ACRONYM LIST

AEC	Atomic Energy Commission
AFAM	Air Force Assigned Mission
ARCHER	Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance
ASPECT	Airborne Spectral Photometric Environmental Collection Technology
CAP	Civil Air Patrol
CAPNOC	CAP National Operations Center
casi	Compact Airborne Spectrographic Imager
DNR	Department Of Natural Resources
EER	Environmental Emergency Response
ENVI	Environment for Visualizing Images
EPA	U.S. Environmental Protection Agency
Fe	Iron
FECA	Federal Employees Compensation Act
FEMA	Federal Emergency Management Agency
FPXRF	Field-Portable X-Ray Fluorescence
GLT	Geographic Lookup Table
GPS	Global Positioning System
HS	Homeland Security
HSI	Hyperspectral Imagery
IGM	Image Geometric Model
IMAGINE	Commercial MSI/HSI analysis application
INS	Inertial Navigation System
IR	InfraRed
MDNR	Missouri Department of Natural Resources
MNF	Minimum Noise Fraction
MoNG	Missouri Army National Guard
MoRAP	Missouri Resource Assessment Partnership
MOU	Memorandums of Understanding
MSI	Multispectral Imagery
NAIP	National Agriculture Imagery Program
NGA	National Geospatial-Intelligence Agency
NIMA	National Imagery and Mapping Agency
NOC	National Operations Center
OA	Office of Administration
OSWER	Office Of Solid Waste And Emergency Response
Pb	Lead
PPI	Pixel Purity Index
PPM	Parts Per Million
PM	Project Managers
RMS	Root Mean Square
SAM	Spectral Angle Mapper
SEMA	State Emergency Management Agency
SCC	Space Computer Corporation
UMC	University of Missouri at Columbia
USGS	U.S. Geological Survey
WEC	Westinghouse Electric Company
WSSRAP	Weldon Spring Site Remedial Action Project